UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D. C. 20555

December 2, 1987

MEMORANDUM FOR: D. W. Moeller, Chairman
ACRS Subcommittee on Waste Management

FROM: O. S. Merrill, Senior Staff Engineer O.S.Merrill

SUBJECT: DRAFT RESPONSES TO QUESTIONS GENERATED DURING THE JULY 29, 1987 MEETING OF THE ACRS SUBCOMMITTEE ON WASTE MANAGEMENT WITH DOE AT LAS VEGAS, NV

I have just received a copy of a letter from M. Blanchard, DOE (Nevada Waste Management Project Office) to J. Knight, DOE, Director of Licensing and Regulatory Division, HQ, transmitting draft responses to the subject questions. As explained by Mr. Blanchard, since it has taken such a long time for the project staff to prepare these responses, rather than delaying their transmittal longer, he elected to send me a draft copy concurrent with its submission to Mr. Knight. Consequently, with this memorandum, I am sending you a copy of all the materials just received. A list of the enclosures is provided as Attachment A.

Please advise me of any further action you may wish to take regarding these responses.

Enclosures:
Attachment A and Documents Listed Thereon

cc: With Attachment A and all Enclosures:

ACRS Members:	ACRS Consultants:
C. Mark	M. Carter
F. Remick	K. Krauskopf
P. Shewmon	F. Parker
M. Steindler	M. Trifunac
S. Parry, ACRS Sr. Fellow	

With Attachment A and Enclosures 1 and 7 only:
Other ACRS Members
ACRS Technical Staff
Other ACRS Fellows

ATTACHMENT A

List of Documents Enclosed

1. Transmittal Letter for J. P. Knight from M. B. Blanchard, dated November 19, 1987.

2. Enclosure 1: Draft of Questions and Answers, with list of References (undated)

3. Enclosure 2: Calculation of the Probability of Volcanic Disruption of a High-Level Radioactive Respository Within Southern Nevada, USA, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 3(2), December 1982, pp. 167-190.

4. Enclosure 3: Ground Motion Evaluations at Yucca Mountain, Nevada With Applications to Repository Conceptual Design and Siting, Contractor Report SAND 85-7104, printed February 1986.

5. Enclosure 4: Technical Basis and Parametric Study of Ground Motion and Surface Rupture Hazard Evaluations at Yucca Mountain, Nevada, Report SANDS 86-7013, printed December 1986.

6. Enclosure 5: Summary Report on the Geochemistry of Yucca Mountain and Environs, Report LA-9328-MS, Issued December 1982.

7. Enclosure 6: Excerpt from Vieth, D. L., Letter to J. William Bennett on the subject of the NNWSI Project's response to the proposed 10 CFR 60 Unsaturated Zone Amendment (49 FR 5934); April 2, 1984.

8. Enclosure 7: Draft letter of transmittal of Enclosures 1 through 6 above for O. S. Merrill from M. Blanchard (undated)

Enclosure 7

Department of Energy
Post Office Box 98518
Las Vegas, NV 89193-8518

DRAFT

Owen S. Merrill
Senior Staff Engineer
Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
1717 H. Street NW (H/SH-1016)
Washington, DC 20555

RESPONSE TO QUESTIONS GENERATED DURING THE JULY 29, 1987, MEETING OF THE ADVISORY COMMITTEE ON REACTOR SAFEGUARDS (ACRS) SUBCOMMITTEE ON WASTE MANAGEMENT, THE STATE OF NEVADA NUCLEAR WASTE PROJECT OFFICE, AND THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS (NNWSI) PROJECT

At the conclusion of the July meeting, the U.S. Department (DOE) of Energy agreed to provide additional information regarding some topics raised but not discussed at length during the meeting. The Chairman of the ACRS Subcommittee, Dr. Moeller, requested that the project develop questions based on these discussions which could be answered in a single page of text, excluding any enclosures. The project formulated nine questions and responses as a result of these discussions.

Subsequently, the project received a copy of Dr. Moeller's Trip Report dated August 15, 1987, in which he reported that six questions were posed and he noted that the subcommittee encouraged the DOE to focus on protecting the health and safety of the public as well as the environment, in addition to meeting the Nuclear Regulatory Commission regulations.

The DOE has compared the nine questions formulated by the project with the six questions reported by Dr. Moeller and found that the questions address identical subjects. The questions formulated by the NNWSI Project tend to expand the questions as reported in Dr. Moeller's Trip Report. For example, two questions were posed by the project concerning performance allocation and performance assessment, while Dr. Moeller combined these concepts in a single question. The DOE has responded to each of the questions in Enclosure 1. To avoid any confusion, both the NNWSI Project's and the ACRS Subcommittee's statement of each question as reported by Dr. Moeller has been reprinted before each response.

Please contact me at FTS 575-8939 or Mary Lou Brown of Science Applications International Corporation at FTS 575-8658, if further clarification is desi:

for Maxwell B. Blanchard, Chief
Regulatory & Site Evaluation Branch
Waste Management Project Office

WMPO:MBB-250

Enclosures:
1. NNWSI Project's Responses to Questions
2. Calculation of the Probability of Volcanic Disruption of High-Level Radioactive Waste Repository
3. Ground Motion Evaluation at Yucca Mountain
4. Technical Basis and Parametric Study
5. Summary Report on Geochemistry
6. Excerpt from the NNWSI Project's Response to the Proposed 10CFR60 Unsaturated Zone Amendment

cc w/encl 1:
T. O. Hunter, SNL, 6310, Albuquerque, NM
Scott Sinnock, SNL, 6315, Albuquerque, NM
F. W. Bingham, SNL, 6312, Albuquerque, NM
J. R. Tillerson, SNL, 6314, Albuquerque, NM
L. R. Hayes, USGS, Denver, CO
K. F. Fox, USGS, Denver, CO
W. E. Wilson, USGS, Denver, CO
L. D. Ramspott, LLNL, Livermore, CA
V. M. Oversby, LLNL, Livermore, CA
D. T. Oakley, LANL, Los Alamos, NM
J. A. Canepa, LANL, Los Alamos, NM
M. E. Spaeth, SAIC, Las Vegas, NV
Gerald Frazier, SAIC, Las Vegas, NV
Jerry King, SAIC, Las Vegas, NV
T. A. Grant, SAIC, Las Vegas, NV
S. R. Mattson, SAIC, Las Vegas, NV
D. A. Chestnut, SAIC, Las Vegas, NV
M. D. Voegele, SAIC, Las Vegas, NV
M. A. Glora, SAIC, Las Vegas, NV
C. G. Pflum, SAIC, Las Vegas, NV
D. M. Dawson, SAIC, Las Vegas, NV
M. L. Unger, SAIC, Las Vegas, NV
M. L. Brown, SAIC, Las Vegas, NV
D. B. Jorgenson, SAIC, Las Vegas, NV
J. L. Younker, SAIC, Las Vegas, NV

cc w/encls:
J. P. Knight, HQ (RW-24) FORS
S. H. Kale, HQ (RW-20) FORS
P. T. Prestholt, NRC, Las Vegas, NV
R. R. Loux, NWPO, Carson City, NV

cc w/o encls:
V. J. Cassella, HQ (RW-222) FORS

Enclosure 1

Question 1. Practically all of the elements that go into the performance assessment have enormous variability and uncertainty. How do you propose to convince scientists that the performance assessments are accurate?

ACRS Statement of this Question: As previously indicated, the procedures for determining the performance allocations for various parameters within the HLW repository should be carefully documented and provided to the Subcommittee.

Strictly, the accuracy of performance calculations is not a material issue; rather the probabilities associated with failure of the site to meet performance criteria and protect the public must be known with some degree of confidence, expressed by the Commission as "reasonable assurance."

The credibility of performance calculations depends on the degree of confidence attributable to the conceptual models being applied, the reasonableness of mathematical and numerical expressions of the conceptual models, and the accuracy of variables used in numerical solutions with respect to site conditions, including spatial variability.

It is likely that several mutually exclusive conceptual models and their respective data sets could be used to assess the performance of the site. Similarly, different mathematical and numerical techniques can be used to describe each of the models. Finally, different ways of interpreting the observed data may be equally credible. Our strategy for building confidence in our quantitative predictions of site behavior, particularly its likelihood of failure, includes (1) use of several credible conceptual models that encompass a wide range of potential site behavior; (2) evaluation of the accuracy of the calculation performed by computer codes for each model by code verification and benchmarking; (3) generation of multiple "realizations" (predictions) of site behavior to account for uncertainty and variability in site properties; and (4) calibration of model predictions with data obtained at the site. The probabilities of failure associated with the various models, solution techniques, and data interpretations may vary significantly. These alternative failure probabilities can be combined to generate a joint probability density function, or they can be considered separately.

This approach deals primarily with numerical, quantitative predictions of site behavior and has limited facility to quantify the inevitable residual uncertainty associated with models or the data. To address the crux of the question posed above, our strategy for building confidence also relies heavily on professional judgments about our predictions. We will continue to solicit peer review of our approach and implementing techniques to ensure that no obvious failure modes are being overlooked and, to borrow the Commission's words "to foster a common technical understanding and to resolve issues, where it is practicable to do so, prior to receipt of a license application" (Federal Register, vol. 51, no. 118, page 22292, June 19, 1986).

The final disposition of the issue of accuracy or reliability for performance assessments depends on judgments made by the Commission, in light of supporting judgments made by several other parties, including those of your committee. We intend to build a basis for these judgments by exposing our approach to the full scrutiny of the technical community. We are confident that we can establish a basis for "reasonable assurance" that the site will meet all performance criteria and, with the same evidence, convince the technical community of the reasonableness of our conclusions, though we cannot predict such an outcome with certainty.

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Question 2: If only bounding values can be obtained (a distribution of the values cannot be obtained due to their variability), how will you do a probabilistic analysis?

ACRS Statement of the Question: As previously indicated, the procedures for determining the performance allocations for various parameters within the HLW repository should be carefully documented and provided to the Subcommittee.

The purpose of a probabilistic analysis is to quantify a state of knowledge or, its reciprocal, uncertainty. In general probabilistic analysis, the special case represented by bounding values is one where the information is limited to maximum and (or) minimum values of the independent variables. The bounding values for some parameters may, and in all likelihood will, be used as point values in conjunction with probability distributions of other parameters to generate a probability distribution of performance. Such a probabilistic analysis, even one that includes bounding values for some variables, can and probably will be augmented by bounding analyses that rely exclusively on bounding values. However, the prudence of bounding analyses must be carefully considered in view of the tendency of such analyses to shift predictions toward incredible, unrealistic values. The Commission has clearly recognized the role of both bounding and "best estimate" predictions in providing a basis for judgments about site suitability in an environment of considerable technical uncertainty. We share the Commissions views on this subject as described in the Federal Register on June 19, 1986 (vol. 51, no. 118, page 22293). By judicious use of both bounding and probabilistic analyses, we hope to provide a defensible basis for "reasonable assurance" that the performance criteria can be met, and that public health may be maintained.

DRAFT

Question 3: Provide information regarding water table fluctuations induced by underground nuclear explosions.

ACRS Statement of the Question: Indications are that the underground nuclear weapons tests have altered (temporarily and/or long range) the water tables in the area. Data on these changes should be provided.

Data exists for wells located near the sites of underground nuclear explosions, however, it is not clear if the observed change in water levels represent increases of the water-table altitude or merely pressure increases in the formation. The following information was taken from an USGS Open File Report 76-313; "1976 Field Trip to Nevada Test Site," p. 45-49.

Fluid-pressure response to several nuclear events has been measured by placing pressure transducers in boreholes, often with the water column confined by inflatable packers. The first effect is an oscillatory pressure response to seismic signals generated by the explosion. The Handley event (March, 1970), an explosion having a yield slightly greater than 1 megaton, produced a dynamic ground-water overpressure of more than 300 feet in drill hole UE20f (fig. 1), about 3 miles from the event site. In Clayton Valley, 71 miles northwest of the Handley site, the oscillatory head change was less than 3 feet but produced surges of more than 100 gpm in some open wells.

Sustained pressure changes, resulting from compaction of the rocks around the explosion and from closing of fractures by seismic stresses, were recorded for more than a month after the Handley event. In drill hole UE20p (figs. 1 and 2), about 3 miles north of the event site, a sustained pressure rise of 164 feet occurred 4 days after Handley.

Similar effects result from the lower yield explosions beneath Yucca Flat. The Bilby event (U3cn) in Area 3 (September, 1963), having a reported yield of approximately 200 kt, caused the fluid level to rise about 250 feet in an observation well, 2,000 feet from the explosion site (fig. 3). It is not known whether these observed water levels represent increases of the water-table altitude or merely pressure increases that dissipate slowly in the relatively impermeable tuffs. In either case, they indicate explosion-caused hydraulic mounds that may be responsible for the surprisingly high water levels found in some exploratory and emplacement holes drilled near earlier explosion sites.

While this data exists for the NTS, no data has yet been published concerning the effects of underground nuclear explosions on water level fluctuations or pressure changes at wells near Yucca Mountain. The NNWSI Project recognizes the importance of understanding the hydrologic system and has initiated efforts to analyze and interpret data that has been taken from wells in the vicinity of Yucca Mountain. The Project expects to publish a report entitled "Estimates of Aquifer Characteristics from Water- Level Fluctuations Induced by Earth Tides and Barometric Fluctuations" early next year. In addition, data reports containing water-level data, well and test hole descriptions, pertinent well histories, descriptions of the data collection procedures, and indications of data accuracy and precision will be published periodically as data become available.

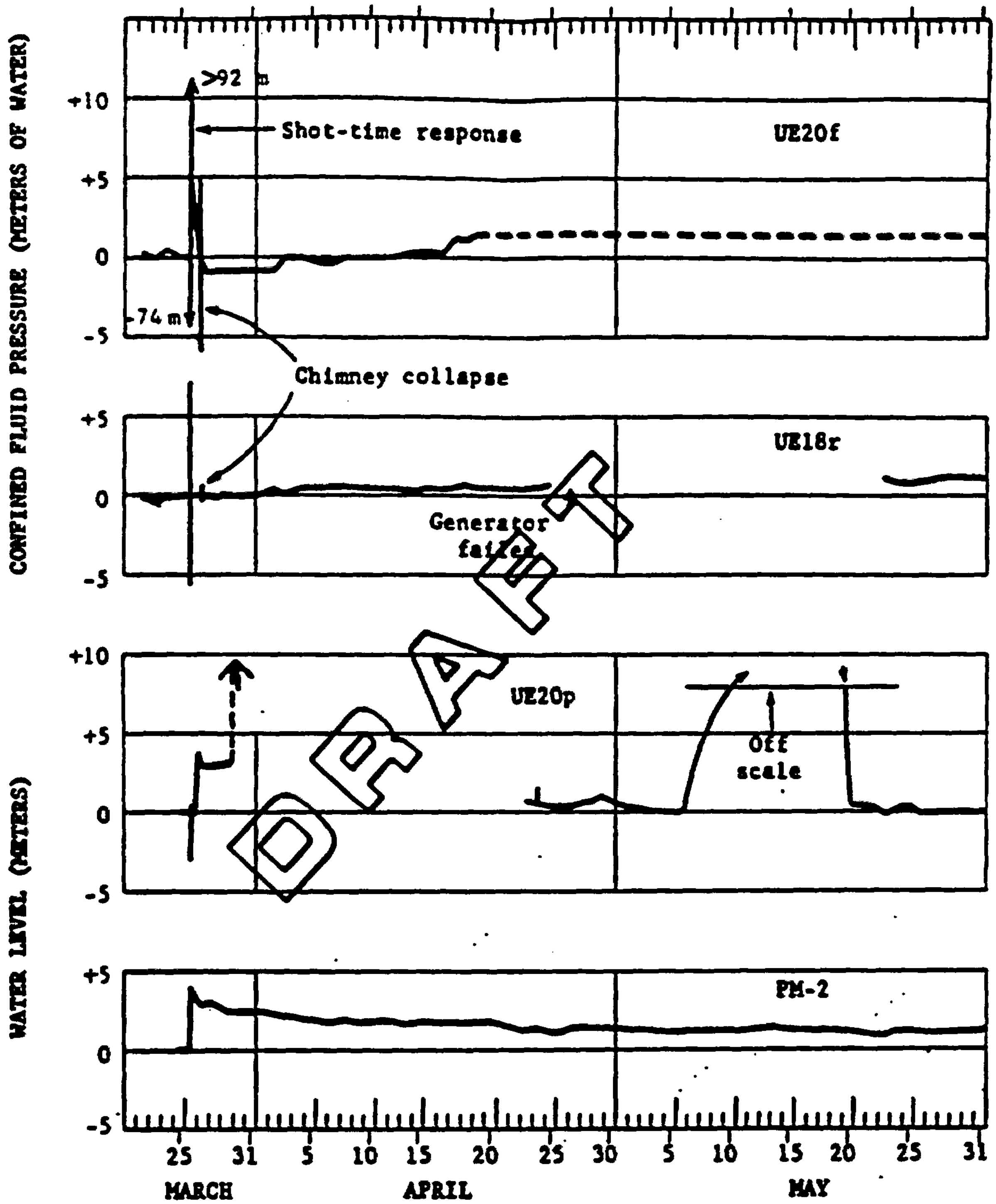

Figure 1 - Confined fluid pressures in holes UE20F and UE18r, and water levels in holes UE20p and PM-2 after the Handley event.

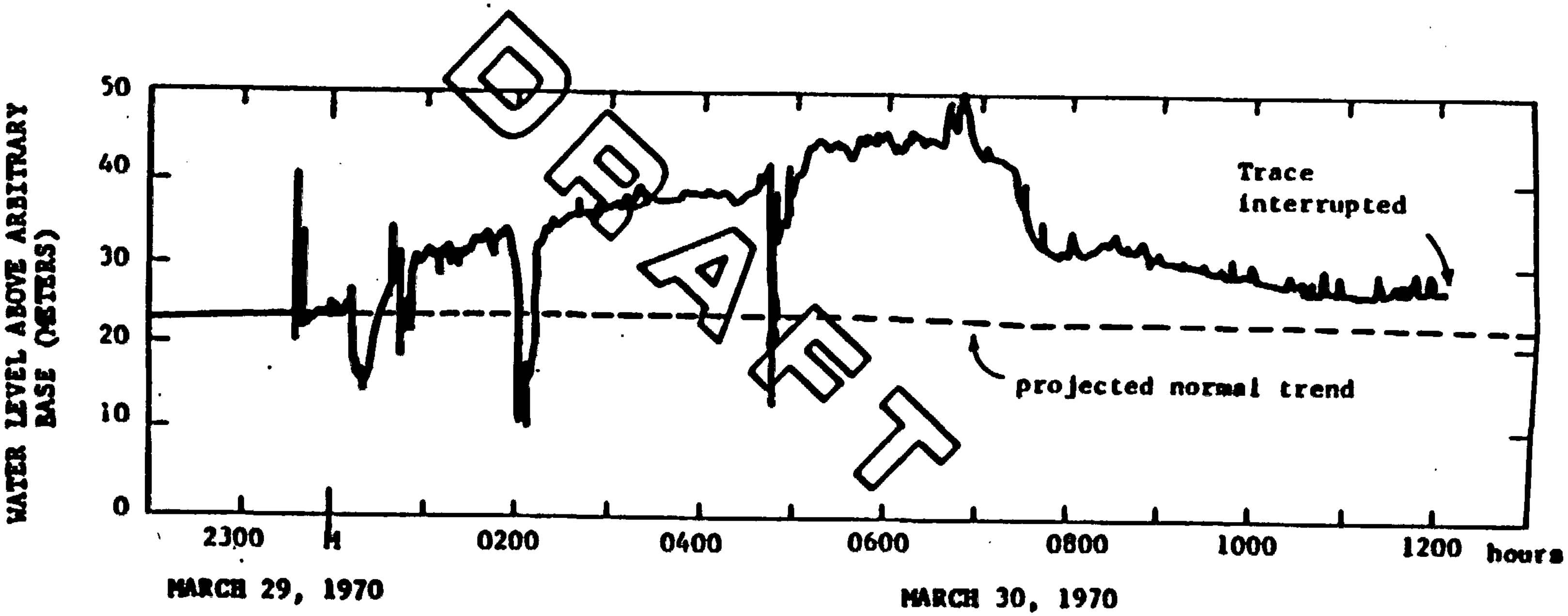

Figure 2 - Tracing of the UE20p water-level record of March 29-30, 1970.

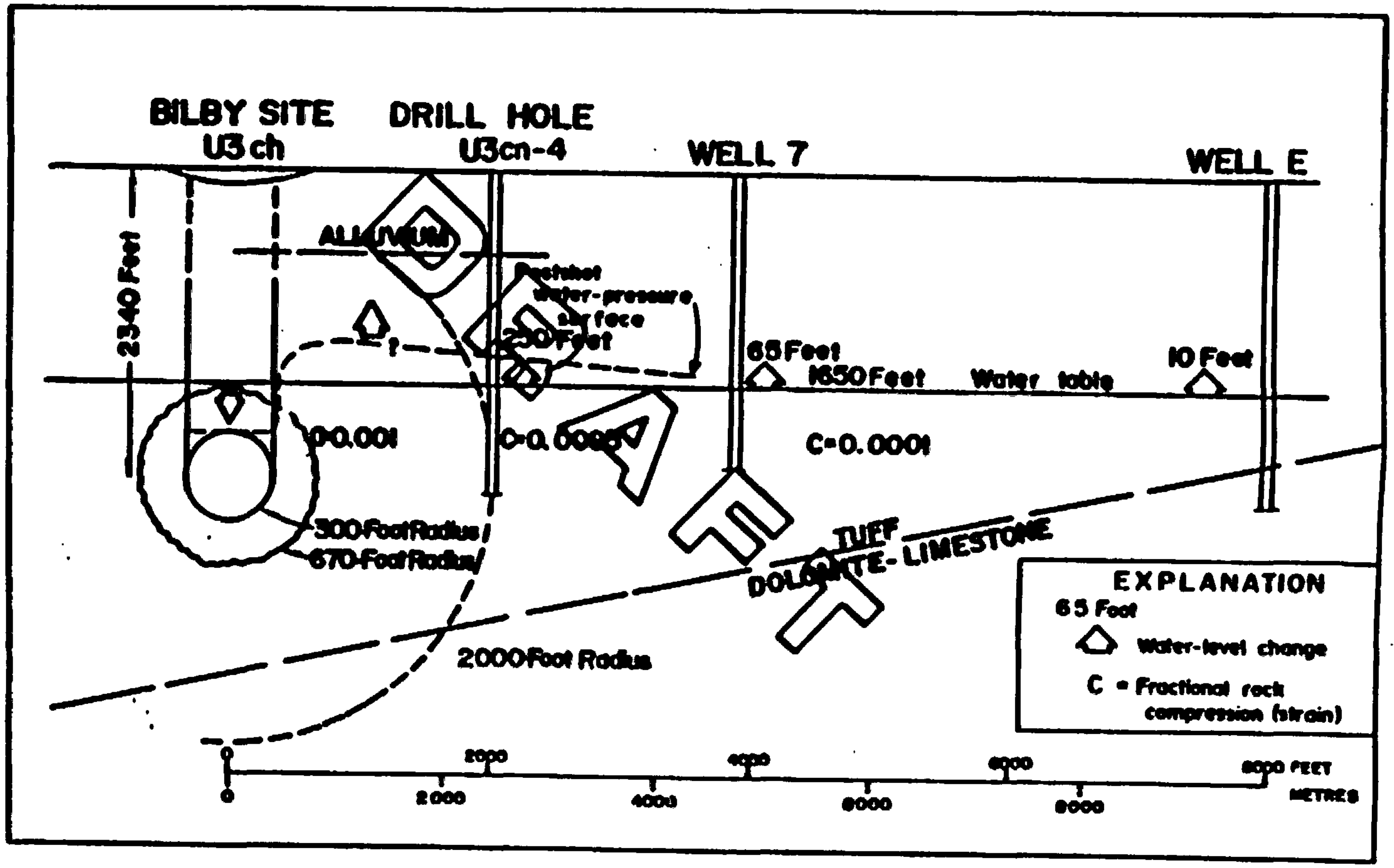

Figure 3 - Pore-pressure response to the Bilby event, September 1963.

Question 4: Discuss the stress field surrounding Yucca Mountain and provide information on the impact of UNE's on the stress field

ACRS Statement of the Question: The same information is needed regarding measurements of stress fields in the area. Where did the numbers come from? Details of the calculations should be provided.

In the southern Great Basin the regional stress field at seismogenic depths is relatively uniform with respect to the locations of recorded earthquakes (Zoback and Zoback, 1980). However, shallow stress measurement investigations at Yucca Mountain indicate a stress field that differs somewhat from the regional stress field. Mechanisms that may contribute to this difference include topographic effects, spatial variation of the material properties of the uppermost crust in the vicinity of the site, and local faulting including possible detachment faulting.

In the discussion that follows, the larger and smaller components of the principal stresses in the horizontal plane are referred to as SH and Sh, respectively. The component in the vertical plane is referred to as Sv.

Rogers et al. (1987) examined comprehensive data for 1522 earthquakes in the Sourthern Great Basin and observed correlations between epicenter lineations, focal mechanism nodal planes, and mapped structural grain. They concluded that faults in the region of Yucca Mountain which strike from north to east-northeast could be considered favorably oriented for activity in the current stress regime. Three styles of faulting were observed from focal mechanisms, depending on fault orientation. These styles were dextral, sinistral, and normal, on north, east-northeast, and northeast trending faults respectively. Dextral is the predominant deformation mode. They concluded that the intermediate and greatest principal stresses have about equal magnitude through the brittle crust. This conclusion is not in accord with stresses measured by hydraulic fracturing at Yucca Mountain. Rogers et al. further observed that average earthquake energy release rates at Yucca Mountain are three orders of magnitude lower than regional levels. Two interpretations of that observation were presented. First, the Yucca Mountain region (extending west nearly to the Furnace Creek-Death Valley fault zone) could be a region of low stress due to either some form of tectonic decoupling or previous prehistoric seismic energy release. Second, this area could be analogous to a seismic gap where stress accumulates and the faults are locked at the present time. The lack of seismicity, the apparent disparity between the inferred regional stresses and the stresses at Yucca Mountain measured by hydraulic fracturing, and the geologic data that suggest the possibility of detachment faulting at Yucca Mountain are consistent with the conclusion that Yucca Mountain is decoupled from the regional stress field; however, other interpretations are possible as described below.

At Yucca Mountain and vicinity, Sh trends N 50-65 W, based on earthquake focal mechanisms, the orientation of drilling-induced fractures, in situ stress measurements, and the orientation of borehole breakouts. In situ stresses were measured in four deep boreholes at Yucca Mountain (USW G-1, USW G-2, USW G-3, and Ue25 p#1) using hydrofrac methods. These measurements have shown that the relationship between the magnitudes of Sh, SH, and Sv is: Sh < SH < Sv. From these measurements, the gradient or increase of Sh with depth appears to be in the lower part of the range generally observed for this parameter, and gives rise to values of Sh that are close to those at which slip occurs on properly oriented fault planes (trending N 25 E, dipping 60 to 67 degrees) under the influence of gravity, if the coefficient of friction is at the lower extreme of the range (0.6 to 1.0) generally associated with this parameter (Stock et al., 1985).

The reported measurements at Yucca Mountain contrast with in situ stress measurements at Rainier Mesa (45 km northeast of Yucca Mountain) and Climax Stock (12 km east of Rainier Mesa) where on average, Sh < Sv < SH. Focal mechanisms of small earthquakes scattered throughout the Yucca Mountain region suggest strike-slip faulting (with exceptions) probably indicating that Sh < S < SH at seismogenic depths. At some locations both normal faulting and strike-slip mechanisms are observed, indicating that Sh < Sv = SH.

Stress measurements in the region of Yucca Mountain show a relatively consistent northwest orientation of the minimum horizontal principal stress. As noted, Rogers et al. (1987) concluded that the greatest and intermediate principal stresses were approximately equal; they described the stress state as axially symmetric (about the axis of the minimum principal stress). An alternative hypothesis concerning the apparent variation of the stress field with depth at Yucca Mountain, is that the shallow stress field at Yucca Mountain is actually consistent with the conclusion of Rogers et al. (1987) within the accuracy of the hydraulic fracturing techniques used by Stock et al. (1985). A number of assumptions were made in the performance of the hydrofrac measurements at Yucca Mountain, such as orientation of the principal stresses and the method used to calculate SH, that have a significant effect on the calculated value for the intermediate stress (SH). These questions will be examined during continuing investigations about stresses in the vicinity of Yucca Mountain.

Opinion is divided as to the extent to which the measured stress values in eac drillhole (generally six to eight measurements) are representative of the entire thickness of rock penetrated by each drillhole. These tests were conducted in relatively unfractured zones that were identified using core, borehole television, and the borehole acoustic televiewer (in the saturated zone). If the stress field at Yucca Mountain is accurately represented by the hydrofrac measurements in the four drillholes tested to date, then the variation from the deeper stress field represented by earthquake focal mechanisms and from measurements at the Rainier Mesa-Climax Stock area may be due to geometrical effects including topography, lateral and vertical variatio in material properties, tectonic effects, or some combination. The existing data which describe natural seismicity (i.e. earthquake focal mechanisms) are insufficient to either confirm or deny the different possibilities. Until additional data become available, it will not be possible to unequivocably explain the apparent variation in tectonic mechanisms with depth.

There is also disagreement as to the contribution of topographic effects to the measured shallow in situ stresses at Yucca Mountain. Stock and Healy (in press) concluded that "topographic influence on the measured Sh values is too small to be detected." However, Swolfs et al. (in press) evaluated the measured stresses using a two-dimensional model that incorporates topography and concluded that "measured stresses at shallow depths in the saturated zone are affected by fracture-induced anisotropy, and selectively, by topography." Bauer et al. (1985) used finite element analysis of a gravity loaded model to assess the effects of topography and stratigraphic variation of mechanical properties. Their models showed that calculated values for shallow in situ stress were sensitive to both effects. Further work (Bauer and Holland, 1987) refined the model to include tectonic stress, and also found agreement with stress measurements at Yucca Mountain. These models did not address the stress state at seismogenic depths.

Detailed studies of in situ stress at Rainier Mesa indicate that the elastic constants and magnitude of in situ stress vary significantly from layer to layer in the bedrock sequence. The bedrock sequence at Yucca Mountain is qualitatively similar to that at Rainier Mesa, inplying that elastic constants and in situ stress could vary from layer to layer at Yucca Mountain as well.

Possible tectonic effects that could be responsible for differences in the stress state with depth are numerous. Depositional histories for the tuffs could be a cause of stress differences, particularly as Yucca Mountain has depositional sheets overlying older faults. The location of Yucca Mountain (an Rainier Mesa) relative to the caldera structures evident at the NTS is another possible cause. The calderas may act as inclusions in the uppermost crust, and stress concentrations around the inclusions could contribute to variation in the shallow stress field (Cummings, 1968). Movement of faults can redistribute stresses on a regional scale. Strike-slip normal and possible detachment faulting could affect the stress state.

The low magnitude of Sh observed from hydrofrac measurements indicates that th apertures of fractures oriented perpendicular to Sh may be sensitive to variation of in situ stress and to changes in pore pressure. Thus, the nature of water movement through fractures either from surface infiltration and through the unsaturated zone, or in the saturated zone, may depend on the stress state.

Underground nuclear explosions (UNEs) generally trigger release of tectonic stress only in the close vicinity of the UNE (Hamilton, 1972). The equivalent fault model of triggered stress release following the HANDLEY event at Pahute Mesa corresponded to a dextral strike-slip fault trending N 15 W (Wallace et al., 1985). The Sh-axis implied by the focal mechanism was about N 60 W, similar to that of post-shot earthquakes reported by Hamilton (1972). Release of tectonic stress in the area of the UNEs may affect the state of stress at Yucca Mountain, however, the magnitude of that effect has not been observed or estimated.

References

Bauer, S. J., J. F. Holland and D. K. Parrish, 1985, "Implications about in situ stress at Yucca Mountain," 26th U.S. Symposium on Rock Mechanics, Rapid City, SD, June 1985, pp. 1113-1120.

Bauer, S. J. and J. F. Holland, 1987, "Analysis of in situ stress at Yucca Mountain," 28th U.S. Symposium on Rock Mechanics, Tucson, AZ, June 1987, pp. 707-713.

Cummings, D., 1968, "Mechanical Analysis of the Effect of the Timber Mountain Caldera on the Basin and Range Faults," JGR, V.73, N.8, pp. 2787-2794.

Hamilton, R. M., B. E. Smith, F. G. Fisher and P. J. Papanek, 1972, "Earthquakes caused by underground nuclear explosions on Pahute Mesa, Nevada Test Site," BSSA, V.62, N.5, pp.1319-1341.

Rogers, A. M., S. C. Harmson and M. E. Meremonte, 1987, "Evaluation of the Seismicity of the Southern Great Basin and its relationship to the tectonic framework of the region," USGS, OFR (in final review)

Stock, J. et al. (in prep.)

Swolfs, H., et al. (in prep.)

Wallace, T. C., D. V. Helmberger and G. R. Enger, 1985, "Evidence of Tectonic Release from Underground Nuclear Explosions in Long Period S Waves," BSSA, V.75, N.1, pp. 157-174.

Zoback, M. L. and M. Zoback, 1980, "State of Stress in the Conterminous United States," JGR, V.85, N.B11, pp. 6113-6156.

Question 5: Provide references on specific steps involved in calculating probabilities relevant to volcanic studies and ground motion studies.

ACRS Statement of the Question: The same information is needed regarding measurements of stress fields in the area. Where did the numbers comes from? Details of the calculations should be provided.

The following reports are enclosed (Enclosures 2, 3, and 4) and address specific steps involved in calculating probabilities relevant to volcanic studies and ground motion studies.

Crowe, B. M. et al., "Calculation of the Probability of Volcanic Disruption of a High-Level Radioactive Waste Repository Within Southern Nevada, USA," Radioactive Waste Management and the Nuclear Fuel Cycle, vol. 3(2), December 1982. (Enclosure 2)

URS/John A. Blume & Associates, "Ground Motion Evaluations at Yucca Mountain, Nevada with Applications to Repository Conceptual Design and Siting," SAND85-7104, February 1986. (Enclosure 3)

URS/John A. Blume & Associates, "Technical Basis and Parametric Study of Ground Motion and Surface Rupture Hazard Evaluation at Yucca Mountain, NV," SAND86-7013, December 1986. (Enclosure 4)

Question 6: Provide information on retardation coefficients, sorption and geochemistry experiments that are being done or are planned. Include colloid migration and solubility measurements.

ACRS Statement of the Question: How were the retardation coefficients determined? In fact, could more information be provided on all the geochemistry work from the standpoint of how it was assured that collected samples were representative, that their analyses were accurate, and that the interpretation of the resulting data were properly conducted.

A great deal of information about geochemical studies at Yucca Mountain can be found in Daniels, et. al. (1982). Work completed since that time is included in a series of technical quarterly reports listed in the reference section. A summary of all sorption measurements made through 1985 will be published as Los Alamos National Laboratory report LA-10960-MS later this year. However, the best source of summary information on sorption and solubility studies is found in Chapters 4 and 8.3.1.3 of the Site Characterization Plan for Yucca Mountain, Nevada.

As the SCP will not be published until early in 1988, we have attempted to summarize information regarding the geochemistry program in the following discussion prepared by Los Alamos National Laboratory. Daniels et. al. (1982) is also enclosed (Enclosure 5).

SUMMARY OF THE GEOCHEMISTRY PROGRAM AT LOS ALAMOS

INTRODUCTION

The geochemistry test program at Los Alamos contributes geochemical expertise and scientific support in studying, assessing, and evaluating the chemical and physical processes expected to affect migration of radionuclides along potential transport pathways. The test program is an integrated effort that consists of five main areas of experimental work, the purpose of which is to

1) provide information on the solution chemistry of radionuclides under conditions expected in the far-field repository area (solubility, speciation, colloid formation, and stability);

2) investigate the geochemical retardation process of sorption (Kd) by studying sorption as a function of groundwater composition, mineralogy, and concentration of sorbing species, and by studying sorption on particulates and colloids;

3) investigate the sorption process, the potential for colloid transport, and the physical processes of diffusion and dispersion in a dynamic system;

4) investigate the natural geochemical system by studying the groundwater chemistry, the mineralogy and petrology along potential flow paths, and the stability of the minerals; and

5) develop conceptual models (groundwater chemistry, mineral evolution, sorption, geochemical/physical model of Yucca Mountain) and numerical models (transport models) and evaluate, synthesize, and integrate the data generated by the test program.

PAST WORK

Chapter 4 of the Site Characterization Plan discusses the retardation mechanism of sorption, provides basic dynamic transport information, and includes information on the coupling of absorption to dynamic processes. Furthermore, this chapter contains data and a discussion on the solubility of radionuclides and the potential for colloid formation and transport, important parameters or processes for an analysis of radionuclide retardation.

The methods and procedures used to investigate geochemical retardation and estimates of the attendant uncertainties are discussed in detail by Daniels et al, (1982) and in Sections 4.1.3.2.1 through 4.1.3.2.5 of the Site Characterization Plan. A general overview of the experimental techniques used is given in the following text, which is taken from Chapter 4 of the Site Characterization Plan.

The simplest mathematical approach to absorption is to use the distribution coefficient, Kd. The measurement of Kd allows the characterization of tuffs with different mineralogies. In a manner similar to that used for chromatographic columns, the samples are crushed to a predetermined size fraction (typically between 75 and 500 micrometers) and carefully mixed to ensure homogeneity (on a small scale). The crushed samples will allow rapid equilibration. The heterogeneity of the tuff strata at Yucca Mountain requires a significant number of measurements to characterize the sorptive properties. The limitations of the distribution coefficient approach to geologic investigations are as follows:

1) The assumption of a linear sorption isotherm. The terms sorption isotherm, Freundlich isotherm, or Langmuir isotherm are generally used to define the relationships between sorption and the concentration of the element being sorbed at a constant temperature.

2) The distribution between the solid phase and the aqueous phase may include precipitation or irreversible reaction or both.

3) The aqueous-phase species are not well known for many of the important radionuclides, and the formation of radiocolloids contributes to the uncertainty.

4) The assumption of equilibrium (i.e., rapid kinetics).

These limitations do not necessarily apply to all the radionuclides of importance. For example, the solution chemistry of the alkali metals and the alkaline earths is well known, and the aqueous-phase species can be predicted with certainty. Average values are calculated for measured sorption ratios since measurements are made in duplicate.

Three sorption procedures have been used: batch, circulating column, and crushed tuff column. These three sorption procedures are discussed thoroughly in Sections 4.1.3.2.2, 4.1.3.2.3, and 4.1.3.2.4 of the Site Characterization Plan and in many of the references cited in the attached bibliography.

Batch sorption methods approach equilibrium distribution coefficients for long-term experiments and yield information on kinetics for short-term experiments and on reversibility by desorption experiments. They are easy to conduct, but "equilibrium" sorption values may not be representative of a flowing system. The batch technique, in spite of its simplicity, is not without experimental pitfalls. To ensure that discrepancies between laboratory experiments are not due to experimental errors, the following is carefully controlled:

1) Phase separation. When distribution coefficients (Kd) are high, the experiments are susceptible to contamination of the aqueous phase with colloidal material containing radionuclides; this contamination leads to erroneously low Kd values.

2) Water composition. Comparison between experiments using radically different water compositions leads to large discrepancies.

3) Crushing and sieving. The rock must not be crushed below mineral crystal size and the samples should be sieved to ensure uniformity. (For tuff, surface area does not appear to correlate with cation exchange capacity or particle size; Daniels et al., 1982, Wolfsberg et al., 1979).

4) Mineral fractionation. This can occur either in the process of sieving or in the course of an experiment, such as a crushed tuff column, because the sorbing minerals (clays and zeolites) in tuff generally have small crystal sizes that will enrich in the smaller size fractions.

5) Speciation. The results of experiments where the complexing agents or redox conditions are not identical will show discrepancies for some radionuclides.

The above parameters must be controlled to study the distribution of geochemical properties in the geologic system. Where these cannot be made to coincide exactly with the conditions in the field, compromises are made in a conservative direction for applying the results to predictions in the field. For example, the smallest size fractions are discarded, oxidizing conditions are used, etc. To systematically study which simplifying assumption may be valid and to experimentally examine the coupling of absorption to dynamic processes, the following types of experiments have been performed:

1) Crushed tuff columns. The experiments allow the comparison of batch to transport through nearly identical material; they allow the study of kinetic effects, speciation and other physical and chemical effects, such as anion exclusion. The advantage in using crushed tuff is that the results are free of ambiguities in the interpretation that would occur if the effect of heterogeneity and dispersion was not minimized.

2) Recirculating columns. The experiments were performed to test whether self-grinding, which might produce extremely small particles when stirred, had occurred in batch measurements. The technique is otherwise subject to nearly the same pitfalls as batch measurements.

3) Solid tuff columns. The experiments have been and will continue to be performed to examine the validity of batch sorption measurements on tuff where homogeneity and dispersion are not controlled. The hydrologic flow is more constrained than that in the field. The filtration of colloids will also be studied to examine the potential for particulate migration.

4) Fractured tuff columns. The experiments represent the most complex transport system that can be simulated in the laboratory. The chemical process of sorption and the physical processes of diffusion and dispersion are investigated. (The transport of particulates and colloids by fracture flow also will be investigated).

5) Diffusion in solid tuff. The experiments are ancillary to the fractured tuff columns but provide fundamental data for modeling diffusion in the tuff matrix. The experiments will also provide some kinetic data.

6) Solubility. The experiments are primarily directed toward understanding actinide solution chemistry in near-neutral solution and toward investigating the formation and stability of radiocolloids, specifically colloids of plutonium and americium. The understanding of actinide chemistry under near-neutral conditions is growing at a very slow pace because the low solubility of these elements does not allow the direct determination of oxidation state and molecular structure.

PLANNED STUDIES

Future work in the solubility, sorption, and dynamic transport tasks will concentrate on the solubility and speciation of the actinide elements, radiocolloid formation, stability and transport, mechanistic studies of the sorption process, and continued fractured tuff column experiments.

A stumbling block to understanding the sorption and transport of actinides, is the inability to identify the species (oxidation states and complexes) present in solution at the concentration levels expected underground (<10-6M). Chemical methods of identifying plutonium species have produced unsatisfactory results; however, new methodologies have been identified that remain unpursued. The speciation data are considered critical to the understanding of radionuclide retardation; without being able to identify actinide species at very low concentration, we are unable to identify those species that do not sorb or to characterize the species in solution. Plans are being made to pursue the new methodologies, and to technically integrate the methodologies with the experimental program.

Our increased effort to understand the formation and stability of radiocolloids is part of the solubility task. In this regard, we are preparing a report entitled "Colloid Stability and Characterization," which discusses the formation, characterization, and stability of plutonium (IV) colloid. This work is an important precurser to understanding and interpreting the results of colloid transport experiments (fractured tuff column work) and actinide sorption experiments.

These specific areas of technical focus highlight a larger integrated research effort, the results of which must characterize the geochemical environment at Yucca Mountain and demonstrate our understanding of the site. This characterization must contribute to our geosphere transport model which, to the degree possible, provides the most rigorous simulation of the Yucca Mountain transport process and the overall effectiveness of geochemical barriers to waste isolation.

Plans for future work in the integrated Geochemistry Test Program can be found in Section 8.3.1.3 of the Site Characterization Plan; however, detailed study plans are not yet available.

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Question 7: How can radionuclide migration studies from underground nuclear explosions help in understanding how to predict radionuclide migration from a repository?

ACRS Statement of the Question: ACRS did not record this as a question; the topic was discussed in conjunction with the previous question.

The Radionuclide Migration Program (RMP) at both Los Alamos National Laboratory and Lawrence Livermore National Laboratory has been underway for many years. There are several important differences between studying the radionuclide migration observed from an underground nuclear explosion and that from a repository. This includes the differences in the type and amounts of radionuclides present, the concentrations of radionuclides present, the geologic system, and the effects on the surrounding rock produced by an explosion versus the long-term effects a repository may have (e.g., thermal pulse from waste emplacement). However, analysis of the data from the RMP has suggested several potential areas of study and allows comparisons by analogy to be made for the Nevada Nuclear Waste Storage Investigations Project.

The types of information that can be obtained from sites of underground nuclear tests include information on the dissolution of blast-produced glass containing radionuclides and the migration of solutions containing radionuclides through tuffacious rocks. Examinations of complex natural systems are not likely to aid in the development of basic models on dissolution, sorption, and transport, but rather can aid in the validation of models developed from laboratory testing on basic physical and chemical processes and controlled field testing. The possibility of radionuclide transport by colloids is being actively studied in the radionuclide migration program.

Plutonium is present in the glass produced as a result of a nuclear test in concentrations similar to those planned to be present in glass waste forms for storage. Although the glass compositions are different, examination of glasses recovered from test locations may be useful in the validation of models of the long-term dissolution behavior of plutonium-bearing glass. Tests have been conducted both above and below the water table and cover a fairly long time span, thus it may be possible to validate the release of plutonium from glass as a function of time and solution flux.

From the analysis of water samples, in conjunction with pumping tests of drillholes located near explosion sites, information may be gained on radionuclide (e.g., especially plutonium) transport, solubility, sorption, and speciation through a tuff rock/water system. The concentrations of radionuclides in the pumped solutions will be the result of solubility limitations imposed by the local environment and sorption reactions along the transport path. By sampling water that flows through different transport paths and for different distances it may be possible to separate the two effects. In addition, the distribution of uncharged species (tritium, Kr-85), cations (Sr-90, Cs-137), and anions (Cl-36, I-129) may yield information concerning potential transport paths and mechanisms.

In summary, the ultimate application of information gained from underground nuclear testing may aid in the validation of models developed through detailed laboratory and controlled field testing programs designed specifically for the Yucca Mountain environment. A listing of recent publications relevant to this subject follows.

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Question 8: Is NRC's criterion for groundwater travel time (GWTT) a useful measure of the repository's performance, particularly a repository in the unsaturated zone?

ACRS Statement of this Question: Which is important -- the travel time of the groundwater or the radionuclides that it contains? The DOE staff is to clarify its questions regarding this issue and the Subcommittee will seek a response from the NRC Staff.

The DOE does not believe that ground-water travel time represents an appropriate measure of performance for a site within the unsaturated zone. The flux through the repository, both in the unsaturated and saturated zones, is a more appropriate and direct measure of potential cumulative releases to the accessible environment. The amount of water moving past the wastes is one of the primary factors which sets a limit, independent of flow velocity, flow path, or travel time, on the maximum number of curies of a particular radionuclide that can be released from a repository and subsequently be transported by ground water to the accessible environment. DOE notes that Dames & Moore reached essentially the same conclusion in NUREG/CR-3130 when they concluded that flux and the frequency of wetting events were the primary factors in determining releases from wastes disposed in the unsaturated zone.

The DOE believes an alternative performance objective for the geologic setting for a repository located in the unsaturated zone is appropriate in that the volumetric flow rate (flux) of ground water through a geologic repository located in the unsaturated zone is the most important factor in determining the performance of the repository. Enclosed with this response is an excerpt from the NNWSI Project's response to the proposed 10 CFR 60 unsaturated zone amendment (49FR5934), dated April 2, 1984, which explains the rationale for this (flux) approach in greater detail (enclosure 6).

The DOE also notes that for this calculation to be meaningful, it should represent the rock conditions applicable at the time for which the calculations are meant to be representative, rather than use a disturbed zone assumed to be 50m in size along with the thermal-mechanical changes caused to the rock by the introduction of waste canisters. During the pre-waste emplacement period rock conditions are only disturbed as a result of excavation, not heat from emplaced waste canisters. Rock features that are likely to change during excavation that could impact the pre-waste emplacement ground-water travel time include porosity, permeability, and stress. The rock that will be studied during the testing phase of the exploratory shaft will be the best characterized and most understood rock anywhere within, or beyond, the repository. If changes in rock properties are only found within a few centimeters from the drift wall on the basis of these tests, then we will have ample evidence that the changes are minor, or nonexistent, farther out.

Finally, it should be noted that many questions have been raised concerning the practical application of the current criterion for groundwater travel time.

These questions include:

1) Is the measure of travel time a deterministic or probabilistic value?

2) How should we define "the fastest path of likely radionuclide travel?"

3) Is such a path geographically restricted to a single potential flow tube or distributed throughout the site?

4) In defining the "fastest path" can we consider the relative or absolute volume of groundwater moving along the path (e.g., Can we include volume as a probabilistic element for demonstrating compliance with the GWTT objective?)

5) Can a path be excluded if it crosses the disturbed zone but does not reach the waste? Even if the path reaches the waste, can it be excluded if it is not a groundwater conduit? (e.g., Must we assume that every fracture through the disturbed zone is a water pathway even though there is only remote possibly that the fracture will ever contain groundwater).

We hope that these questions and the enclosed alternative performance objective will clarify the importance of groundwater travel time and its relationship to radionuclide transport in the unsaturated zone.